SPECIFICATION

TITLE OF THE INVENTION

MULTICARRIER CDMA TRANSMISSION SYSTEM AND TRANSMISSION METHOD

This application is a continuation of international application number PCT/JP01/07451, filed August 30, 2001 and is still pending.

BACKGROUND OF THE INVENTION

This invention relates to a multicarrier CDMA transmission system and transmission method. More particularly, the invention relates to a multicarrier CDMA transmission system and transmission method for subjecting transmit data to a serial-to-parallel conversion, multiplying each symbol of the obtained parallel data individually by each code constituting orthogonal codes, and multicarrier-transmitting each result of multiplication by a prescribed subcarrier.

Multicarrier modulation schemes have become the focus of attention as next-generation mobile communication schemes. Using multicarrier modulation not only makes it possible to implement wideband, high-speed data transmission but also enables the effects of frequency-selective fading to be mitigated by narrowing the band of each subcarrier. Further, using orthogonal frequency division multiplexing not only makes it possible to raise the efficiency of frequency utilization but also enables the effects of inter-symbol interference to be eliminated by providing a guard interval for every OFDM symbol.

(a) in Fig. 10 is a diagram useful in describing a multicarrier transmission scheme. A serial/parallel converter 1 converts serial data to parallel data and inputs the parallel data to orthogonal modulators 3a to 3d via D/A converter 2a to 2d, respectively. In the Figure, the conversion is to parallel data comprising four symbols. Each symbol includes an in-phase component and a quadrature component. The orthogonal modulators 3a to 3d subject each of the symbols to orthogonal modulation by subcarriers having frequencies f_1 to f_4 illustrated in (b) of Fig. 10, a combiner 4 combines the orthogonally modulated signals and a

transmitter (not shown) up-converts the combined signal to a high-frequency signal and then transmits the high-frequency signal. With the multicarrier transmission scheme, the frequencies are arranged, as shown at (b),

5 in such a manner that the spectrums will not overlap in order to satisfy the orthogonality of the subcarriers.

In orthogonal frequency division multiplexing, frequency spacing is arranged so as to null the correlation between a modulation band signal

10 transmitted by an nth subcarrier of a multicarrier transmission and a modulation band signal transmitted by an (n+1)th subcarrier. If we assume that a symbol (a complex baseband signal) transmitted by the nth subcarrier (center frequency: fn) is represented by zn

15 (= an + jbn), then we may write modulation band signal sn(t) = Re[zn exp(j2π fn t)] (where Re represents the real part of the complex number). The requirement for the (n+1)th subcarrier to be orthogonal to the nth subcarrier is that the cross correlation between sn(t)

20 and sn+1(t) be 0. If the frequency spacing between neighboring subcarriers is fd and the period of the symbol zn is T, then, in order for the cross correlation to become 0, it will suffice for fd = k/T (k = 1, 2, $\cdots$) to hold and the minimum spacing will be

25 fd = 1/T. A multicarrier multiplexing scheme having frequency spacing is an orthogonal frequency division multiplexing scheme.

(a) of Fig. 11 is a diagram of the structure of a transmitting apparatus that relies upon the orthogonal

30 frequency division multiplexing scheme. A serial/parallel converter 5 converts serial data to parallel data comprising a plurality of symbols (I+jQ, which is a complex number). An IDFT (Inverse Discrete Fourier Transform) 6, which is for the purpose of

35 transmitting the symbols as subcarriers having a frequency spacing shown in (b) of Fig. 11, applies an inverse discrete Fourier transform to the frequency

data to effect a conversion to time data, and inputs the real and imaginary parts to an orthogonal modulator 8 through D/A converter 7a, 7b. The orthogonal modulator 8 subjects the input data to orthogonal

5 modulation, and a transmitter (not shown) up-converts the modulated signal to a high-frequency signal. In accordance with orthogonal frequency division multiplexing, a frequency placement of the kind shown in (b) of Fig. 11 becomes possible, thereby enabling an

10 improvement in the efficiency with which frequency is utilized.

In recent years, there has been extensive research in multicarrier CDMA schemes (MC-CDMA) and application thereof to next-generation wideband mobile

15 communications is being studied. With MC-CDMA, partitioning into a plurality of subcarriers is achieved by serial-to-parallel conversion of transmit data and spreading of orthogonal codes in the frequency domain. Owing to frequency-selective fading,

20 subcarriers distanced by their frequency spacing experience independent fading on an individual basis. Accordingly, by causing code-spread subcarrier signals to be distributed along the frequency axis by frequency interleaving, a despread signal can acquire frequency-

25 diversity gain.

An orthogonal frequency / code division multiple access (OFDM/CDMA) scheme, which is a combination of OFDM and MC-CDMA, also is being studied. This is a scheme in which a signal, which has been divided into

30 subcarriers by MC-CDMA, is subjected to orthogonal frequency multiplexing to raise the efficiency of frequency utilization.

A CDMA (Code Division Multiple Access) scheme multiplies transmit data having a bit cycle T_s by

35 spreading codes C_1 to C_N of chip frequency Tc using a multiplier 9, as shown in Fig. 12, modulates the result of multiplication and transmits the modulated signal. Owing to such multiplication, a $2/T_s$ narrow-band signal

NM can be spread-spectrum modulated to a 2/Tc wideband
signal DS and transmitted, as shown in Fig. 13. Here
Ts/Tc is the spreading ratio and, in the illustrated
example, is the code length N of the spreading code.
5   In accordance with this CDMA transmission scheme, an
advantage acquired is that an interference signal can
be reduced to 1/N.

     According to the principles of multicarrier CDMA,
N-number of items of copy data are created from a
10   single item of transmit data D, as shown in Fig. 14,
the items of copy data are multiplied individually by
respective ones of codes C_1 to C_N, which are spreading
codes (orthogonal codes), using multipliers 9_1 to 9_N,
respectively, and products DC_1 to DC_N undergo
15   multicarrier transmission by N-number of subcarriers of
frequencies f_1 to f_N illustrated in (a) of Fig. 15.
The foregoing relates to a case where a single item of
symbol data undergoes multicarrier transmission. In
actuality, however, as will be described later,
20   transmit data is converted to parallel data of M
symbols, the M-number of symbols are subjected to the
processing shown in Fig. 14, and all results of M × N
multiplications undergo multicarrier transmission using
M × N subcarriers of frequencies f_1 to fN_M. Further,
25   orthogonal frequency/code division multiple access can
be achieved by using subcarriers having the frequency
placement shown in (b) of Fig. 15.

     Fig. 16 is a diagram illustrating the structure on
the transmitting side of MC-CDMA. A data modulator 11
30   modulates transmit data and converts it to a complex
baseband signal (symbol) having an in-phase component
and a quadrature component. A time multiplexer 12
time-multiplexes the pilot of the complex symbol to the
front of the transmit data. A serial/parallel
35   converter 13 converts the input data to parallel data
of M symbols, and each symbol is input to a spreader 14
upon being branched into N paths. The spreader 14 has

M-number of multipliers 14_1 to 14_M. The multipliers 14_1 to 14_M multiply the branched symbols individually by codes C_1, C_2, $\cdots$, C_N constituting orthogonal codes and output the resulting signals. As a result, subcarrier

5 signals S_1 to S_{MN} for multicarrier transmission by N × M subcarriers are output from the spreader 14. That is, the spreader 14 multiplies the symbols of every parallel sequence by the orthogonal codes, thereby performing spreading in the frequency direction. Codes

10 that differ for every user are assigned as the orthogonal codes used in spreading.

In the case of a downlink (transmission by a base station), a code multiplexer 15 code-multiplexes the subcarrier signals generated as set forth above and the

15 subcarriers of other users generated through a similar method. That is, for every subcarrier, the code multiplexer 15 combines the subcarrier signals of a plurality of users conforming to the subcarriers and outputs the result. A frequency interleaver 16

20 rearranges the code-multiplexed subcarriers by frequency interleaving, thereby distributing the subcarrier signals along the frequency axis, in order to obtain frequency-diversity gain. An IFFT (Inverse Fast Fourier Transform) unit 17 applies an IFFT to the

25 subcarrier signals that enter in parallel, thereby effecting a conversion to an OFDM signal (a real-part signal and an imaginary-part signal) on the time axis. A guard-interval insertion unit 18 inserts a guard interval into the OFDM signal, an orthogonal modulator

30 applies orthogonal modulation to the OFDM signal into which the guard interval has been inserted, and a radio transmitter 20 up-converts the signal to a radio frequency, applies high-frequency amplification and transmits the resulting signal from an antenna.

35 The total number of subcarriers is (spreading ratio N) × (number M of parallel sequences). Further, since fading that differs from subcarrier to subcarrier

is sustained on the propagation path, a pilot is time-multiplexed onto all subcarriers and it is so arranged that fading compensation can be performed subcarrier by subcarrier on the receiving side. The time-multiplexed

5   pilot is a common pilot that all users employ in channel estimation. In case of uplink, the signals of each of the users are combined on the propagation path and received at a base station.

Fig. 17 is a diagram useful in describing a

10   serial-to-parallel conversion. Here a common pilot P has been time-multiplexed to the front of transmit data. If the common pilot is 4 × M symbols and the transmit data is 30 × M symbols, then M symbols of the pilot will be output from the serial/parallel converter 13 as

15   parallel data the first four times, and thereafter M symbols of the transmit data will be output from the serial/parallel converter 13 as parallel data 30 times. As a result, the pilot can be time-multiplexed into all subcarriers and transmitted. By using this pilot on

20   the receiving side, fading compensation becomes possible on a per-subcarrier basis.

Fig. 18 is a diagram useful in describing insertion of a guard interval. If an IFFT output signal conforming to M symbols is taken as one unit,

25   then guard-interval insertion signifies copying the tail-end portion of this symbol to the leading-end portion thereof. Inserting a guard interval GI makes it possible to eliminate the effects of inter-symbol interference ascribable to multipath.

30   Fig. 19 is a diagram showing structure on the receiving side of MC-CDMA. A radio receiver 21 subjects a received multicarrier signal to frequency conversion processing, and an orthogonal demodulator subjects the receive signal to orthogonal demodulation

35   processing. A timing-synchronization / guard-interval removal unit 23 establishes receive-signal timing synchronization, removes the guard interval GI from the

receive signal and inputs the result to an FFT (Fast Fourier Transform) unit 24. The FFT unit 24 converts a signal in the time domain to N × M-number of subcarrier signals. A frequency deinterleaver 25 rearranges the subcarrier signals in an order opposite that on the transmitting side and outputs the signals in the order of the subcarrier frequencies.

After deinterleaving is carried out, a fading compensator 26 performs channel estimation on a per-subcarrier basis using the pilot time-multiplexed on the transmitting side and applies fading compensation. In the Figure, a channel estimation unit $26a_1$ is illustrated only in regard to one subcarrier. However, such a channel estimation unit is provided for every subcarrier. The channel estimation unit $26a_1$ estimates the influence $\exp(j\phi)$ of fading on phase using the pilot signal, and a multiplier $26b_1$ multiplies the subcarrier signal of the transmit symbol by $\exp(-j\phi)$ to compensate for fading. A despreader 27 has M-number of multipliers 27_1 to 27_M. The multiplier 27_1 multiplies N-number of subcarriers individually by codes C_1, C_2, $\cdots$, C_N constituting orthogonal codes assigned to users and outputs the results. The other multipliers also execute similar processing. As a result, the fading-compensated signals are despread by spreading codes assigned to each of the users, and signals of desired users are extracted from the code-multiplexed signals by despreading.

Combiners 28_1 to 28_M each add the N-number of results of multiplication that are output from respective ones of the multipliers 27_1 to 27_M, thereby creating parallel data comprising M-number of symbols. A parallel/serial converter 29 converts this parallel data to serial data, and a data demodulator 30 demodulates the transmit data.

Fig. 20 is an explanatory view illustrating the state of MC-CDMA fading fluctuation in a downlink from

a base station. A subcarrier signal of a prescribed
user that has been spread along the frequency axis is
code-multiplexed onto the subcarrier signal of another
user and sustains fading that differs for every
5   subcarrier on the propagation path. In the case of an
outgoing call from a base station, however, a code-
multiplexed subcarrier signal of a different user
sustains the same fading FD12 on each subcarrier. As a
result, if fading compensation is carried out using
10   channel estimation information estimated for every
carrier by means of the pilot symbol, fading sustained
by each user can be compensated for simultaneously, as
indicated by FD12', orthogonality of the spreading
codes of each of the users can be maintained and user
15   signals will not interfere with one another.
Accordingly, using a code having a high degree of
orthogonality as the spreading code is extremely
effective in an MC-CDMA scheme.
        In the uplink, however, each user experiences
20   different degrees of fading F1, F2 as shown in Fig.21.
Consequently, each subcarrier signal experiences
independent fading user by user and orthogonality of
the spreading code of each user is lost completely.
For example, even if fading fluctuation F1 with respect
25   to user 1 is compensated for by a fading compensator in
the manner indicated at F1', fading fluctuation F2 with
respect to user 2 becomes as indicated at F2'.
Accordingly, in a case where the MC-CDMA scheme for
performing spreading in the frequency domain is applied
30   to the uplink, a large deterioration in characteristics
occurs.
        Further, there are instances where a directional
beam is emitted from a base station toward each user to
transmit data. In such an instance it is necessary to
35   provide an antenna array and carry out beam forming by
causing a beam former to apply an array weight, which
differs for every user, to the transmit data. Fig. 22
is a simple structural view of beam forming and

illustrates an array antenna 31, a transmit beam former 32 for controlling the directivity of the beam by changing the array weight, and transmitters 33_1 to 33_N for inputting transmit signals to antenna elements ATT_1 to ATT_N that construct the array antenna. The transmit beam former 32 controls the array weight in accordance with the direction of the user (mobile station), thereby transmitting the beam toward the user upon changing the magnitude and phase of the transmit signal applied to each antenna element.

In a case where a signal to which a weight that differs for every user has been applied is code-multiplexed in order to implement beam forming, each subcarrier will sustain fading that differs for every user, in a manner similar to that the uplink in Fig. 21, if this signal traverses a propagation path that experiences multipath fading. In particular, the larger the angular spread of multipath, the more the fading experienced by each user is different from and independent of that of other users. Even when beam forming is carried out, therefore, the orthogonality of spreading codes is lost and the characteristic deteriorates significantly. If the array weight of each user has been decided in such a manner that the beam will not be directed toward other users in this case, the interference component toward other users is suppressed and therefore the problem of loss of spreading-code orthogonality is eliminated. In actuality, however, the side lobes of the beam interfere with other users and, hence, the influence of deterioration of characteristics due to loss of orthogonality is great.

As shown in Fig. 23, there are also cases where a sector is divided into a plurality, e.g., three, of directional zones A1, A2, A3, and a beam having the same directivity is transmitted by being directed toward those mobile stations MS11 to MS12, MS21 to MS22, MS31 to MS32 present in the same directional zone.

In the case of such beam forming, it is necessary to use an array weight that differs for every directional zone. However, if a signal to which a weight that differs for every directional zone is code-multiplexed and the code-multiplexed signal traverses a propagation path that experience multipath fading, then, in a manner similar to that of Fig. 21, each subcarrier will sustain fading that differs for every directional zone. In such case, fading sustained by users in different directional zones becomes independent, orthogonality of spreading codes is lost and characteristics deteriorate markedly. In this case also, if the array weight of each directional zone has been decided in such a manner that the beam will not be directed toward other directional zones, the interference component toward other users is suppressed and therefore the problem of loss of spreading-code orthogonality is eliminated. In actuality, however, side lobes SB of the beam BM interfere with other users, as shown in Fig. 23, and, hence, the influence of deterioration of characteristics due to loss of orthogonality is great.

Furthermore, in a case where each subcarrier has sustained fading that differs for every user, channel estimation must be performed using an individual pilot for each user in order to compensate for fading. With MC-CDMA, channel estimation must be carried out with regard to each subcarrier before despreading is performed. To separate an individual pilot of each user, there is a method of utilizing the pattern of a pilot and a method of shifting the position along the frequency and time axes of the pilot user by user to thereby effect separation. In either case, power allocated to individual channels decreases as the number of individual channels increases. (a) in Fig. 24 illustrates a case where a common pilot is used and (b) of Fig. 24 a case where individual pilots are used. The power of each individual pilot is one-fourth that of the common pilot. The greater the number of

individual pilots, therefore, the greater the decline in the accuracy of channel estimation. Further, depending upon the placement and position of the pilot pattern, the channel of each subcarrier must be estimated as by finding channel information between pilots (channel estimation information) by interpolation.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to so arrange it that the orthogonality of a spreading code will not be lost even when MC-CDMA transmission is performed on an uplink (i.e., in call origination from a mobile station).

Another object of the present invention is to avoid loss of the orthogonality of a spreading code even when MC-CDMA transmission is performed by applying beam forming in a downlink (i.e., in call origination from a base station).

A further object of the present invention is to realize excellent channel estimation accuracy even when individual pilots are used.

A further object of the present invention is to so arrange it that a narrow-band receiver can be used in MC-CDMA transmission.

In multicarrier transmission in which transmit data is converted to serial data, each symbol of parallel data obtained is output upon being multiplied individually by each code constituting orthogonal codes, and each result of multiplication is transmitted by a prescribed subcarrier, a plurality of subcarriers are assigned on a per-user basis and transmit data of a user is subjected to multicarrier transmission by the subcarriers assigned. If this arrangement is adopted, use is made of subcarriers having frequencies that differs for every user. As a result, interference on other users is eliminated and excellent multicarrier transmission becomes possible.

In this case, M-number of orthogonal codes are

assigned to a user, parallel data comprising M-number of symbols is output by a serial-to-parallel conversion, an ith symbol of the parallel data is multiplied individually by each code constituting ith orthogonal codes, corresponding results of multiplication from among the results of multiplication of multiplication obtained for every symbol are added, and each result of addition is transmitted by the subcarrier assigned. If multicode multiplexing is thus performed, excellent multicarrier transmission that will not interfere with other users can be performed even with few subcarriers assigned to a user or even if the data transmission rate is high.

Further, multicarrier transmission is carried out upon assigning a plurality of subcarriers exclusively to each user. If this arrangement is adopted, interference upon other users is eliminated and excellent multicarrier transmission becomes possible even in a case where, in a downlink, a base station executes transmit beam-forming processing user by user and transmits the transmit data of each user upon performing frequency multiplexing. Further, in an uplink, interference upon other users is eliminated and excellent multicarrier transmission becomes possible by having the user transmit the transmit data to a base station by multicarrier transmission using the subcarriers assigned.

Further, the same subcarriers are assigned to a plurality of users, different orthogonal code is assigned to each of these users and code multiplexing is performed on the same subcarriers to send the transmit data of each user. If this arrangement is adopted, interference upon other users is eliminated and excellent multicarrier transmission becomes possible even in a case where beam forming is applied to a plurality of users present in the same directional zone and a multicarrier transmission is made from a base station using the same subcarriers.

Further, in a multicarrier transmission, a user
extracts, by filtering, a receive signal component of a
frequency domain of subcarriers that have been assigned
to this user and performs demodulation processing using
5 the extracted receive signal component. If this
arrangement is adopted, multicarrier reception can be
performed using a narrow-band receiver. Further, by
performing transmission by dispersing subcarriers along
the frequency axis using frequency interleaving, it can
10 be so arranged that errors will not concentrate. This
makes it possible to improve error-correction
performance.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram useful in describing a first
15 principle of the present invention;

Fig. 2 is a diagram useful in describing a second
principle of the present invention;

Fig. 3 is a block diagram of the transmitting side
of a mobile station in the case of an uplink when
20 subcarriers are assigned exclusively on a per-user
basis;

Fig. 4 is a block diagram of the receiving side of
a base station according to a first embodiment;

Fig. 5 is a block diagram of the transmitting side
25 of a base station in a case where beam forming is used
in a downlink;

Fig. 6 is a block diagram of the receiving side of
a mobile station in a case where a base station
transmits data by an MC-CDMA scheme using transmit beam
30 forming;

Fig. 7 is a modification of Fig. 5 for a case
where a frequency interleaver on the transmitting side
has been deleted;

Fig. 8 is a modification of Fig. 6 for a case
35 where a frequency deinterleaver on the receiving side
has been deleted;

Fig. 9 is a block diagram of a base station
according to a third embodiment;

Fig. 10 is a diagram useful in describing a multicarrier transmission scheme;

Fig. 11 is a diagram useful in describing an orthogonal frequency division multiplexing scheme;

Fig. 12 is a diagram useful in describing code spreading modulation in CDMA;

Fig. 13 is a diagram useful in describing spreading of a band in CDMA;

Fig. 14 is a diagram useful in describing the principle of a multicarrier CDMA scheme;

Fig. 15 is a diagram useful in describing placement of subcarriers;

Fig. 16 is a block diagram of a transmitting side in MC-CDMA according to the prior art;

Fig. 17 is a diagram useful in describing a serial-to-parallel conversion;

Fig. 18 is a diagram useful in describing a guard interval;

Fig. 19 is a block diagram of a receiving side in MC-CDMA according to the prior art;

Fig. 20 is an explanatory view illustrating the state of MC-CDMA fading fluctuation in a downlink from a base station

Fig. 21 is an explanatory view of fading fluctuation user by user in a case where an MC-CDMA scheme has been applied to an uplink (origination of a call from a mobile station);

Fig. 22 is a diagram useful in describing beam forming;

Fig. 23 is a diagram useful in describing beam forming in a case where a sector has been divided into a plurality of directional zones; and

Fig. 24 is a diagram useful in describing pilots.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

(A) Overview of the invention

(a) First principle of the invention

Fig. 1 is a diagram useful in describing a first principle of the present invention and illustrates a

case where the number of users is two for the sake of explanation.

According to the present invention, subcarriers of prescribed frequencies are assigned exclusively to each

5   user, as shown in Fig. 1. For example, subcarriers SC_{11} to SC_{1N} are assigned exclusively to user 1 and other subcarriers SC_{21} to SC_{2N} are assigned exclusively to user 2. Further, it is so arranged that multicode multiplexing is performed upon assigning a plurality of

10   spreading codes to the same user. For example, orthogonal codes 1, 2 are assigned to user 1 and orthogonal codes 1, 2 are assigned to user 2.

If the above arrangement is adopted, a user is capable of using specific subcarriers exclusively. As

15   a result, even if the fading characteristic differs for each of the users 1, 2, as indicated at F1, F2 in Fig. 1, there will be no interference between users and therefore the orthogonality of spreading codes will not be lost. Accordingly, by using the present invention,

20   the superior characteristics of MC-CDMA can be maintained even in the case of an uplink and in a case where beam forming is used in a downlink. Furthermore, according to the present invention, a user is capable of using specific carriers exclusively and therefore a

25   pilot that is time-multiplexed onto each subcarrier becomes a user-specific pilot. Moreover, since there will be no interference with the pilots of other users, one's own pilot can be detected reliably even in a case where the number of users increases, and there is no

30   decline in channel estimation accuracy.

Further, a plurality of orthogonal codes are assigned to a user and multicode multiplexing is carried out. For example, orthogonal codes 1, 2 are assigned to user 1 and orthogonal codes 1, 2 are

35   assigned also to user 2. If multicode multiplexing is thus performed, high-speed transmission using only some subcarriers becomes possible without lowering the transmission rate of the user.

Further, Fig. 1 is an explanatory view showing the state before frequency interleaving is performed on the transmitting side or after frequency deinterleaving has been performed on the receiving side. However, by dispersing the subcarriers in sole possession of the users along the frequency axis by a frequency interleaver, frequency-diversity gain can be obtained.

(b) Second principle of the invention

Fig. 2 is a diagram useful in describing a second principle of the present invention and illustrates a case where the number of users is four for the sake of explanation.

Assume that users 1 and 2 sustain identical fading and that users 3, 4 sustain identical fading, as illustrated at F12, F34 in Fig. 2. As such an environment in which identical fading is sustained, consider a case where a base station uses the same directional beam to transmit to a plurality of users, which belong to the same directional zone, by beam forming, as illustrated in Fig. 23.

Under such circumstances, the present invention assigns subcarriers of prescribed frequencies to the users 1, 2, assigns other subcarriers to the users 3, 4, assigns separate orthogonal codes to users to which the same subcarriers have been assigned, and implements MC-CDMA transmission. For example, subcarriers SC_{11} to SC_{1N} are assigned to users 1, 2 and subcarriers SC_{21} to SC_{2N} are assigned to users 3, 4. Further, orthogonal code 1 is assigned to users 1, 3 and orthogonal code 2 is assigned to users 2, 4.

Since the orthogonal codes between the users 1 and 2 (3 and 4) that experience identical fading remain intact, code multiplexing on the same subcarrier can be performed. This MC-CDMA transmission method is applicable to a case where beam forming is carried out in a downlink (an outgoing call from a base station). For example, in a case where users 1 and 2 are present in the same directional zone, a transmission is

performed using the same directional beam. In other words, the array weights used by users 1 and 2 are the same and the same fading is sustained by each user even on a propagation path that experiences multipath fading. Similarly, a transmission is performed using the same directional beam in a case where the users 3, 4 are present in the same directional zone.

In such case there is no interference between users 1, 2 and users 3, 4 because the subcarriers are different. Further, since the fading sustained by the users 1, 2 is the same, orthogonality is not lost. Similarly, since the fading sustained by the users 3, 4 is the same, orthogonality is not lost. This means that excellent MC-CDMA transmission is possible.

(B) First embodiment

Fig. 3 is a block diagram of the transmitting side of a mobile station in the case of an uplink when subcarriers are assigned exclusively on a per-user basis. Fig. 3 illustrates a case where subcarriers SC_{11} to SC_{1N} are used upon being assigned to user 1, and multicode multiplexing is performed upon assigning first and second orthogonal codes C_{11} to C_{1N}, C_{21} to C_{2N} to user 1. The number N of subcarriers possessed exclusively by one user is the same as the spreading rate, and other users also perform multicode multiplexing similarly using other subcarrier sets. The number N of subcarriers possessed exclusively by one user may be a multiple of the spreading rate.

A data modulator 51 modulates transmit data and converts it to a complex baseband signal sequence (symbol sequence) having an in-phase component and a quadrature component. A time multiplexer 52 time-multiplexes the pilot of the plurality of symbols to the front of the transmit data. A serial/parallel converter 53 converts the input data to parallel data of M symbols (M=2 in this embodiment), and the symbols are input to respective ones of first and second spreaders 54_1, 54_2 upon being branched into N paths.

The first spreader 54_1 has N-number of multipliers.
The multipliers multiply the N-number of branched
symbols individually by respective ones of the codes
C_{11}, C_{12}, $\cdots$, C_{1N} constituting the first orthogonal

5   codes and output the resulting signals. Further, the
second spreader 54_2 has N-number of multipliers. The
multipliers multiply the N-number of branched symbols
individually by respective ones of the codes C_{21}, C_{22},
$\cdots$, C_{2N} constituting the second orthogonal codes and

10 output the resulting signals. A combiner 55 has N-
number of adders. Each adder adds the outputs of the
corresponding multipliers in the first and second
spreaders 54_1, 54_2, and the adders output subcarrier
signals S_1 to S_N. The subcarrier signals S_1 to S_N are

15 multicode multiplexed signals obtained by multiplexing
results of spreading the two symbols by respective ones
of the orthogonal codes C_{11} to C_{1N}, C_{21} to C_{2N}.

A frequency interleaver 56 rearranges the code-
multiplexed subcarriers S_1 to S_N by frequency

20 interleaving, thereby distributing the subcarrier
signals along the frequency axis, in order to obtain
frequency-diversity gain. An IFFT unit 57 applies an
IFFT (Inverse Fast Fourier Transform) to the subcarrier
signals that enter in parallel, thereby effecting a

25 conversion to an OFDM signal (a real-part signal and an
imaginary-part signal) on the time axis. A guard-
interval insertion unit 58 inserts a guard interval
into the OFDM signal, an orthogonal modulator (not
shown) applies orthogonal modulation to the OFDM signal

30 into which the guard interval has been inserted, and a
radio transmitter up-converts the signal to a radio
frequency, applies high-frequency amplification and
transmits the resulting signal toward a base station
from an antenna.

35   If the above arrangement is adopted, a user
employs specific subcarriers exclusively and therefore
orthogonality of spreading codes will not be lost even
in a case where fading differs from user to user.

Further, since multicode multiplexing is performed upon assigning a plurality of spreading codes to a user, high-speed transmission using only some subcarriers becomes possible without lowering the transmission rate

5   of the user.

The embodiment of Fig. 3 relates to a case where the serial/parallel converter 53 has output parallel data of M (=2) symbols. However, M=1 or M≥3 may be adopted. The higher the transmission rate, the larger

10   M, i.e., the greater the number of orthogonal codes assigned to a user.

Fig. 4 is a block diagram of the receiving side of a base station according to the first embodiment in which subcarriers are used upon being assigned

15   exclusively user by user. The structure is such that the transmit data from a plurality of users can be demodulated individually.

A radio receiver (not shown) subjects a received multicarrier signal to frequency conversion processing,

20   and an orthogonal demodulator subjects the receive signal to orthogonal demodulation processing and inputs the processed signal to a timing-synchronization / guard-interval removal unit 61. The latter establishes receive-signal timing synchronization, subsequently

25   removes the guard interval GI from the receive signal and inputs the result to an FFT unit 62. The FFT unit 62 converts a signal in the time domain to a number of subcarrier signals. If we let N represent the number of subcarriers assigned exclusively to each user and

30   let m represent the number of users that a single base station can accommodate, then the FFT unit 62 will output $m \times N$ subcarrier signals. A frequency deinterleaver 63 rearranges the subcarrier signals in an order opposite that on the transmitting side and, in

35   the order of the subcarrier frequencies, inputs the first N-number of subcarrier signals to an MC-CDMA receiver 64_1 for user 1, inputs the next N-number of

subcarrier signals to an MC-CDMA receiver 64_2 for user 2, and similarly inputs an mth N-number of subcarrier signals to an MC-CDMA receiver 64_m for user m. The receivers 64_1 to 64_m are similarly constructed and

5   operate in a similar manner. Accordingly, only the operation of the MC-CDMA receiver 64_1 for user will be described below.

        After deinterleaving is carried out, a fading compensator 65 performs channel estimation on a per-

10   subcarrier basis using the pilot time-multiplexed on the transmitting side and applies fading compensation. In the Figure, a channel estimation unit $65a_1$ is illustrated only in regard to one subcarrier. However, such a channel estimation unit is provided for every

15   subcarrier. The channel estimation unit $65a_1$ estimates the influence $\exp(j\phi)$ of fading on phase using the pilot signal, and a multiplier $65b_1$ multiplies the subcarrier signal of the transmit symbol by $\exp(-j\phi)$ to compensate for fading.

20   First and second despreaders 66_1, 66_2 each have N-number of multipliers MPL and one adder ADD. The multiplier MPL of the first despreader 66_1 multiplies N-number of subcarriers individually by codes C_{11}, C_{12}, $\cdots$, C_{1N} constituting the first orthogonal codes

25   assigned to the user, and the adder ADD adds the results of multiplication from each of the multipliers and outputs the result as the first symbol of parallel data. The multiplier MPL of the second despreader 66_2 multiplies N-number of subcarriers individually by

30   codes C_{21}, C_{22}, $\cdots$, C_{2N} constituting the second orthogonal codes assigned to the user, and the adder ADD adds the results of multiplication from each of the multipliers and outputs the result as the second symbol of parallel data.

35   By virtue of the foregoing, a fading-compensated signal is despread by first and second orthogonal codes assigned to each user, and first and second symbols

constituting the parallel data of user 1 is extracted by despreading from the user-multiplexed signals.

A parallel/serial converter 67 converts this parallel data to serial data, and a data demodulator 68 demodulates the transmit data.

In accordance with the first embodiment, a user employs specific subcarriers exclusively. As a result, there is no interference with other user signals and there is no loss of orthogonality. This makes it possible to improve the receive characteristics. In addition, a pilot that is time-multiplexed onto each subcarrier becomes a user-specific pilot. Moreover, since there will be no interference with the pilots of other users, one's own pilot can be detected reliably even in a case where the number of users increases, and there is no decline in channel estimation accuracy.

(C)   Second embodiment

Fig. 5 is a block diagram of the transmitting side (a block diagram of a base station) in a case where beam forming is used in a downlink (origination of a call from the base station). This is a case where a transmission is made by beam forming using a directional beam on a per-user basis. Further, the Figure illustrates a case where N-number of subcarriers SC_{11} to SC_{1N} are used upon being assigned exclusively to user 1, and multicode multiplexing is performed upon assigning first and second orthogonal codes C_{11} to C_{1N}, C_{21} to C_{2N} to user 1. With regard also to other users, N-number of other subcarriers are used upon being assigned exclusively and a plurality of orthogonal codes are assigned to perform multicode multiplexing. The subcarrier signals of each of the users are frequency-multiplexed by a frequency multiplexer 158.

A data modulator 151 modulates transmit data of user 1 and converts it to a complex baseband signal sequence (symbol sequence) having an in-phase component and a quadrature component. A time multiplexer 152 time-multiplexes the pilot of the plurality of symbols

to the front of the transmit data. In order to
transmit by pointing a beam in a direction in which the
user 1 is present, a beam forming unit 153 branches an
input symbol to four paths, multiplies each branched

5   symbol by array weights W_1 to W_4 and inputs the results
of multiplication to MC-CDMA units 154_1 to 154_4 for
antennas 1 to 4 constituting an array antenna. The
array weights W_1 to W_4 are decided in a controller (not
shown) by detecting the direction of the mobile station

10   and making the decision so as to transmit the beam in
this direction. Since this technique is well known, it
will not be described here in detail. Further, since
the MC-CDMA units 154_1 to 154_4 are identically
constructed and operate in the same manner, only the

15   operation of MC-CDMA unit 154_1 will be described below.

A serial/parallel converter 155 converts the input
data to parallel data of M symbols (M=2 in this
embodiment), and each symbol is input to first and
second spreaders 156_1, 156_2 upon being branched into N

20   paths.

The first spreader 156_1 has N-number of
multipliers. The multipliers multiply the N-number of
branched symbols individually by respective ones of the
codes C_{11}, C_{12}, $\cdots$, C_{1N} constituting the first

25   orthogonal codes and output the resulting signals.
Further, the second spreader 156_2 also has N-number of
multipliers. The multipliers multiply the N-number of
branched symbols individually by respective ones of the
codes C_{21}, C_{22}, $\cdots$, C_{2N} constituting the second

30   orthogonal codes and output the resulting signals. A
combiner 157 has N-number of adders. Each adder adds
the outputs of the corresponding multipliers in the
first and second spreaders 156_1, 156_2, and the adders
output subcarrier signals S_1 to S_N. The subcarrier

35   signals S_1 to S_N are multicode multiplexed signals
obtained by multiplexing results of spreading the two
symbols by respective ones of the orthogonal codes C_{11}
to C_{1N}, C_{21} to C_{2N}.

The frequency multiplexer 158 frequency-multiplexes the subcarrier signals of user 1 and the similarly generated subcarrier signals of the other users, and a frequency interleaver 159 rearranges the code-multiplexed subcarriers by frequency interleaving, thereby distributing the subcarrier signals along the frequency axis, in order to obtain frequency-diversity gain. An IFFT unit 160 applies an IFFT (Inverse Fast Fourier Transform) to the subcarrier signals that enter in parallel, thereby effecting a conversion to an OFDM signal (a real-part signal and an imaginary-part signal) on the time axis. A guard-interval insertion unit 161 inserts a guard interval into the OFDM signal, an orthogonal modulator (not shown) applies orthogonal modulation to the OFDM signal into which the guard interval has been inserted, and a radio transmitter up-converts the signal to a radio frequency, applies high-frequency amplification and inputs the resulting signal to antenna 1 constituting an array antenna. Similarly, signals weighted in accordance with the transmission direction are input to other antennas 2 to 4 constituting the antenna array. As a result, data can be transmitted to user 1 by the directional beam pointing toward user 1, and data can be transmitted similarly to the other users by directional beams pointing toward these other users.

Thus, by carrying out beam forming in a downlink, subcarriers that differ for every user are used even in a case where fading experienced by each user differs. As a result, orthogonality of spreading codes is not lost and the superior characteristics of MC-CDMA schemes can be maintained.

Fig. 6 is a block diagram of the receiving side of a mobile station according to the second embodiment in a case where a base station transmits data by an MC-CDMA scheme using transmit beam forming.

A radio receiver subjects a received multicarrier signal to frequency conversion processing, and an

orthogonal demodulator subjects the receive signal to
orthogonal demodulation processing and inputs the
processed signal to a timing-synchronization / guard-
interval removal unit 171. The latter establishes

5   receive-signal timing synchronization, subsequently
removes the guard interval GI from the receive signal
and inputs the result to an FFT unit 172. The FFT unit
172 converts a signal in the time domain to a number of
subcarrier signals. If we let N represent the number

10   of subcarriers assigned exclusively to each user and
let m represent the number of users that a single base
station can accommodate, then the FFT unit 172 will
output m × N subcarrier signals. A frequency
deinterleaver 173 rearranges the subcarrier signals in

15   an order opposite that on the transmitting side and, in
the order of the subcarrier frequencies, inputs N-
number of subcarriers that have been assigned thereto
to a fading compensator 174.

After deinterleaving is carried out, the fading

20   compensator 174 performs channel estimation on a per-
subcarrier basis using the pilot time-multiplexed on
the transmitting side and applies fading compensation.
In the Figure, a channel estimation unit $174a_1$ is
illustrated only in regard to one subcarrier. However,

25   such a channel estimation unit is provided for every
subcarrier. The channel estimation unit $174a_1$
estimates the influence $\exp(j\phi)$ of fading on phase
using the pilot signal, and a multiplier $174b_1$
multiplies the subcarrier signal of the transmit symbol

30   by $\exp(-j\phi)$ to compensate for fading.

First and second despreaders 175_1, 175_2 each have
N-number of multipliers MPL and one adder ADD. The
multiplier MPL of the first despreader 175_1 multiplies
N-number of subcarriers individually by codes C_{11}, C_{12},

35   ···, C_{1N} constituting the first orthogonal codes
assigned to the user, and the adder ADD adds the
results of multiplication from each of the multipliers

and outputs the result as the first symbol of parallel
data.   The multiplier MPL of the second despreader 175_2
multiplies N-number of subcarriers individually by
codes C_{21}, C_{22}, $\cdots$, C_{2N} constituting the second

5   orthogonal codes assigned to the user, and the adder
ADD adds the results of multiplication from each of the
multipliers and outputs the result as the second symbol
of parallel data.

A parallel/serial converter 176 converts this

10   parallel data comprising two symbols to serial data,
and a data demodulator 177 demodulates the transmit
data.

Figs. 7 and 8 are modifications of Figs. 5 and 6,
respectively, and have structures in which the

15   frequency interleaver and frequency deinterleaver have
been deleted from the base station and mobile station,
respectively.

Since frequency interleaving is not carried out,
it will suffice if the mobile station of Fig. 8

20   executes FFT processing using only the N-number of
subcarriers that have been assigned to it.   To
accomplish this, the mobile station is provided with a
bandpass filter 181, which has a frequency band
conforming to the N-number of subcarriers assigned to

25   this mobile station, in front of the FFT unit 172,
whereby the mobile station is imparted with the
structure of a narrow-band receiver.   If this
arrangement is adopted, FFT having a small number of
stages can be utilized.   This is advantageous in that

30   the processing load of FFT can be mitigated.

(D)   Third Embodiment

Fig. 9 is a block diagram of a base station
according to a third embodiment of the present
invention.   It can be assumed that the mobile station

35   will have a structure similar to that shown in Fig. 6.
The third embodiment is applicable to a case where the
base station transmits, using the same directional beam,
to a plurality of users belonging to the same

directional zone. The Figure illustrates a case where users 1, 2 are present in the same directional zone, N-number of subcarriers conforming to this directional zone have been assigned to users 1, 2, and different

5 sets of orthogonal codes C_{11} to C_{1N}, C_{21} to C_{2N} have been assigned to users 1, 2.

A data modulator 201_1 modulates transmit data of user 1 and converts it to a complex baseband signal sequence (symbol sequence) having an in-phase component

10 and a quadrature component. A time multiplexer 202_1 time-multiplexes the pilot of the plurality of symbols to the front of the transmit data of user 1. In order to transmit by pointing a beam a direction in which the user 1 is present, a beam forming unit 203_1 branches an

15 input symbol to four paths, multiplies each branched symbol by array weights W_1 to W_4 and inputs the results of multiplication to MC-CDMA units 204_1 to 204_4 for antennas 1 to 4 constituting an array antenna.

Similarly, a data modulator 201_2 modulates

20 transmit data of user 2 and converts it to a complex baseband signal sequence (symbol sequence) having an in-phase component and a quadrature component. A time multiplexer 202_2 time-multiplexes the pilot of the plurality of symbols to the front of the transmit data

25 of user 2. It should be noted that the time multiplexer 202_2 can be deleted by adopting a common pilot for users 1, 2. In order to transmit by pointing a beam in a direction in which the user 2 is present, a beam forming unit 203_2 branches an input symbol to four

30 paths, multiplies each branched symbol by array weights W_1 to W_4 and inputs the results of multiplication to the MC-CDMA units 204_1 to 204_4 for antennas 1 to 4 constituting the array antenna.

Since the MC-CDMA units 204_1 to 204_4 are

35 identically constructed and operate in the same manner, only the operation of MC-CDMA unit 204_1 will be described below.

The result of multiplication by weight W_1 that is

output from the beam forming unit 203_1 is branched into N paths and enters a despreader 205_1 for user 1. The spreader 205_1 has N-number of multipliers. The multipliers multiply the N-number of branched symbols individually by respective ones of the codes C_{11}, C_{12}, $\cdots$, C_{1N} constituting the orthogonal codes for user 1 and output the resulting signals. Similarly, the result of multiplication by weight W_1 that is output from the beam forming unit 203_2 is branched into N paths and enters a despreader 205_2 for user 2. The spreader 205_2 has N-number of multipliers. The multipliers multiply the N-number of branched symbols individually by respective ones of the codes C_{21}, C_{22}, $\cdots$, C_{2N} constituting the orthogonal codes for user 2 and output the resulting signals.

A combiner 206 has N-number of adders. Each adder adds the outputs of the corresponding multipliers in the spreaders 205_1, 205_2 of users 1, 2, and the adders output subcarrier signals S_1 to S_N. The subcarrier signals S_1 to S_N are multicode multiplexed signals obtained by multiplexing results of spreading the symbols of users 1, 2 by respective ones of the orthogonal codes C_{11} to C_{1N}, C_{21} to C_{2N}.

A frequency multiplexer 207 frequency-multiplexes the subcarrier signals of users 1, 2 and the similarly generated subcarrier signals of the other users, and a frequency interleaver 208 rearranges the code-multiplexed subcarriers by frequency interleaving, thereby distributing the subcarrier signals along the frequency axis, in order to obtain frequency-diversity gain. An IFFT unit 209 applies an IFFT (Inverse Fast Fourier Transform) to the subcarrier signals that enter in parallel, thereby effecting a conversion to an OFDM signal (a real-part signal and an imaginary-part signal) on the time axis. A guard-interval insertion unit 210 inserts a guard interval into the OFDM signal, an orthogonal modulator (not shown) applies orthogonal modulation to the OFDM signal into which the guard

interval has been inserted, and a radio transmitter up-converts the signal to a radio frequency, applies high-frequency amplification and inputs the resulting signal to antenna 1 constituting an array antenna. Similarly,

5   signals weighted in accordance with the transmission direction are input to the other antennas 2 to 4 constituting the antenna array. As a result, data can be transmitted to users 1, 2 by the directional beam pointing toward users 1, 2, and data can be transmitted

10   similarly to the other users by directional beams pointing toward these other users.

Thus, subcarriers that differ for every user are used even in a case where fading experienced by prescribed users residing in different directional

15   zones differs. As a result, orthogonality of spreading codes is not lost and the superior characteristics of MC-CDMA schemes can be maintained.

The foregoing relates to a case where one orthogonal code is assigned to each user. However, a

20   plurality (=M) of orthogonal codes can be assigned. In such case, one serial/parallel converter and M-number of spreaders are provided for one user and an arrangement similar to that of Fig. 5 is adopted.

Thus, in accordance with the present invention,

25   orthogonality of spreading codes is not lost and excellent characteristics can be obtained in an uplink.

Further, in accordance with the present invention, it is possible to avoid loss of orthogonality and obtain excellent characteristics in a downlink in a

30   case where beam forming is applied.

Further, in accordance with the present invention, excellent channel estimation accuracy can be obtained by using individual pilots.

Further, in accordance with the present invention,

35   a narrow-band receiver can be used, the number of arithmetic stages in FFT can be reduced and the FFT processing load can be mitigated.

Further, in accordance with the present invention,

frequency interleaving is used. As a result, excellent frequency-diversity gain can be obtained even in a case where only some subcarriers are used.